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THE STUDY OF MULTIPACTOR BREAKDOWN IN SPACE ELECTRONIC SYSTEMS

27 JANUARY 1965

THIRD STATUS REPORT

REPORT PERIOD
DECEMBER 1964

Hughes Aircraft Company
Culver City, California

A. OBJECT OF CONTRACT

Multipactor discharges have been observed in a variety of space-borne radio frequency equipment, and are a potential source of system degradation or equipment failure. The object of this study program is to define conditions under which multipactor discharges can occur in representative space hardware, to evaluate the effects of a discharge when it does occur, and to investigate possible techniques for prevention of multipactor which are compatible with other equipment requirements. The work is divided into the following three tasks:

Task I.	Investigate the Multipactor Effects
Task II.	Deleterious Effects of Multipactor
Task III.	Methods of Eliminating Multipactor

B. WORK PERFORMED DURING THE REPORT PERIOD

SUMMARY

This report describes work done during December 1964. Persistent difficulties with the high vacuum experiment setup have prevented its operation, and have delayed the test of specially treated discharge electrodes. Useful results have been obtained from both the harmonic generation and noise generation experiments. Coaxial resonators have been built for use in evaluating the effects of titanium film in suppressing multipactor, and are now under test prior to coating.

DETAILED REPORT

Attempts to operate the high vacuum discharge experiment have so far been frustrated by excessive outgassing of the equipment, and progressively higher bakeout temperatures have been used. As a result it has been necessary to rebuild the RF structure to withstand bakeout at 250°C. This has been done, but in the first process of bakeout the RF feedthrough terminal of the vacuum chamber failed, and the entire setup had to be dismantled for repairs. They have been completed and a new bakeout run has been started. This normally takes four or five days, with the system pumped continually as the oven temperature is increased slowly to the maximum of about 250°C.

Tests of the treated copper electrodes have been delayed because of the problems with the high vacuum equipment, but experiments have been started in the low vacuum chamber using polished beryllium copper discharge plates. Although no useful quantitative data has been taken, preliminary results indicate that these plates will have a much longer active life than any tested previously, and they will be used in future noise and harmonic generation tests.

Measurements of harmonic content of the electron current in a typical discharge were made using the equipment described in the last status report. (See particularly Figures 2a, 2b, and 6.) The 100-mc, 30-watt, crystal-controlled transmitter was used to excite a multipactor discharge in an ambient pressure of about 10^{-5} mm Hg. One channel of the Hewlett-Packard 185A sampling oscilloscope was used to measure the waveform of the electron current collected by an isolated collector plate enclosed in a 4-inch-square shielded box acting as the grounded discharge electrode. The other channel was used to observe the signal from a small pickup plate placed between the electrodes to measure the phase of the applied field in relation to the collector current waveform. The surface of the grounded electrode was pierced with 144 holes 1/16 inch in diameter, so that the collected electron current was about 1/36 of the total electron current in the discharge.

A typical collector current waveform is shown in Figure 1. By graphical Fourier analysis, the following expression was found for the collector voltage:

$$E_{collector} = 666 \sin (wt - 12^{\circ}) + 240 \sin (2\,wt + 77^{\circ}) + 73 \sin (3\,wt + 167^{\circ}) \text{ millivolts}$$

Higher order harmonic terms could not be determined with any certainty.

The analysis shows the negative peaks of the harmonics to be very closely aligned, as would be expected for the arrival of a thin sheet of electrons once each cycle of the applied RF field. Table I gives the extrapolated total discharge current for the first three harmonics.

At the time these measurements were taken the voltage between the discharge plates was about 105 volts rms, and the power dissipation

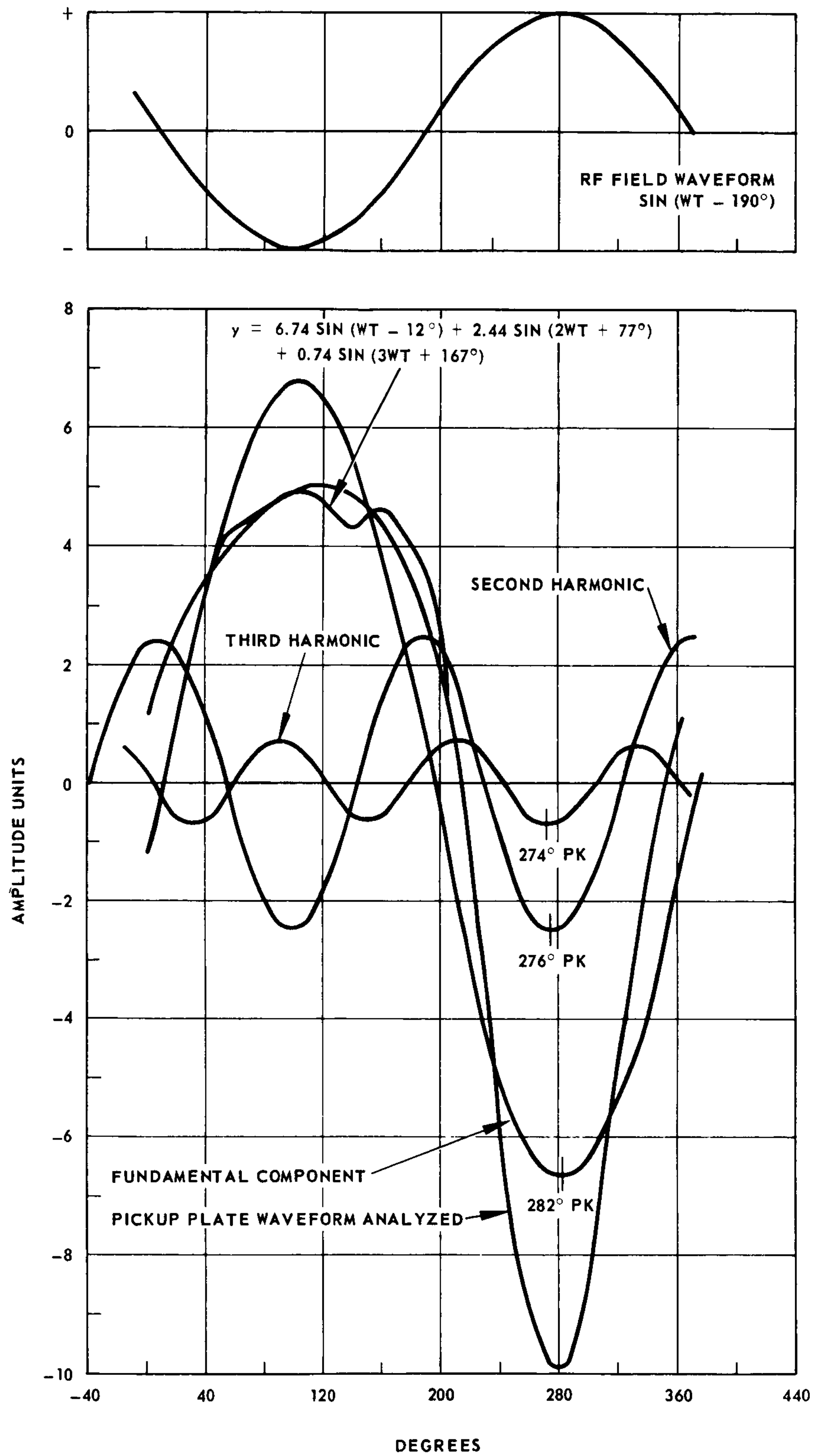

FIGURE 1. FOURIER ANALYSIS OF TYPICAL WAVEFORM

TABLE I

Harmonic	E Peak Volts at Collector	Collector Electrode (I) RMS MA $\frac{E}{50\sqrt{2}}$	Total Discharge Electrode Current RMS MA I(36.2)
Fundamental	0.666	9.43	341
Second	0.240	3.40	123
Third	0.073	1.03	37
Total	--	10.1	364

was about 3 watts. Since the total fundamental electron current was 0.34 amperes, the electron current must have been at a phase of about 85° with respect to the electrode voltage,* and should have caused severe detuning of the RF structure, but this was not observed. This anomalous result has not been explained satisfactorily, and further investigation will be made, since determination of the reactive effects of multipactor discharge is one of the Task I objectives.

One of the interesting results of the harmonic measurements is an evaluation of the second and third order nonlinearity of the discharge current. It should be possible to calculate the amplitude of cross-modulation products in a discharge from the observed magnitudes of these harmonic terms, and this will be done during the next period.

A number of noise generation tests were performed, using the equipment described in the second status report (see Figures 2a and 7 of that report). A 100-mc discharge was generated between a pair of 5-1/2 inch diameter electrodes spaced 3/4 inch. The output signal was

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*Since the real power is VI cos θ,

$$\theta = \cos^{-1}\frac{P}{VI} = \cos^{-1}\frac{3}{0.3 \times 105} \overset{a}{=} 85^{\circ}$$

obtained from a brass pickup plate 3/4 inch x 1-3/8 inch located between the plates and 1/4 inch from the ground potential discharge electrode. The output was connected through a 50-ohm coax line to a 10-db attenuator, the 100-mc band rejection filter, a resistive T mixer, and to a Nems-Clarke type 1306 receiver. After initial trials the receiver was set to the 300-kc IF bandwidth, 100-kc video bandwidth, automatic gain control, and amplitude modulation detector positions for all measurements. The high level video output of the receiver was connected to a Ballantine 643 AC voltmeter. A VHF signal generator was connected to the resistive T network sothat receiver sensitivity could be measured with the transmitter turned on and off. There was no difference in sensitivity, showing that the receiver was not overloaded during the measurements.

Noise level calibration was obtained from a VHF noise source which uses a type TT-1 temperature limited diode with plate current variable over the range from 1 to 100 ma.

Noise power $= q\, I_o b \frac{R}{2} + k\, Tb$ watts, where

$q = 1.6 \times 10^{-19}$ coulomb

$I_o = 10^{-3}$ to 10^{-1} amps (adjustable)

$b = 1$ cps (for watts/cycle)

$R = 50$ ohms

$k = 1.37 \times 10^{-23}$ joule/^oK

$T = 290^oK$

This reduces to:

Noise power $= 4 \times 10^{-19}\, I_o + 0.0397 \times 10^{-19}$ watts/cycle.

Calibration data was taken for each frequency monitored.

The experimental runs were performed at a pressure on the order of 2×10^{-5} mm Hg, the lowest pressure that could be maintained with the outgassing caused by the discharge. For each experiment the pickup plate noise power and discharge input power were measured as a function of the peak RF voltage between the electrodes while operating in vacuum and then the measurements were repeated at atmospheric pressure.

The true multipactor noise power and discharge input power were calculated by taking the difference between measurements in vacuum and the measurements at atmospheric pressure. It was found that the maximum discharge power and brightest glow between the electrodes occurred with about 160 volts peak RF between the electrodes. With voltages above this value the glow spread diffusely through the chamber and noise measurements varied unpredictably. Average values from eight runs taken over a period of two days are given in Figure 2, which shows the linear relation between input power and (peak RF volts squared) for both electrode circuit losses and multipactor power input, over the range from 80 to 140 volts peak.

The noise on the direct pickup plate due to multipactor discharge was detected only at high input power levels, and the noise level was on the order of 10^{-19} watts/cycle or less. Next, a tuned coil was placed in the vacuum chamber with one end grounded and the other connected to the pickup plate. A tap on the coil near the ground end was connected to the 50-ohm coaxial line, as shown in Figure 3. The purpose is to increase the impedance of the pickup plate so that the noise intercepted from a high impedance discharge would increase. To determine the noise intercepted by the plate with the coil, it was necessary to measure the step-down ratio and Q of the tuned circuit by means of a signal generator. The noise intercepted by the plate is

$$N_p = \frac{k^2 N_o \; 50 \; W_o C}{Q_o} \quad \text{watts/cycle}$$

k = voltage step-up ratio of coil

N_o = measured noise level at output of coax (watts/cycle)

W_o = $2\pi f_o$, where f_o is resonant frequency of pickup coil

C = capacitance of tuned circuit

Q_o = resonant Q of pickup coil

Measurements at 56.5, 118, 114, 112, and 110 mc show a decrease in noise level as the separation of the 100-mc discharge frequency and measurement frequency is increased. The tuned circuit

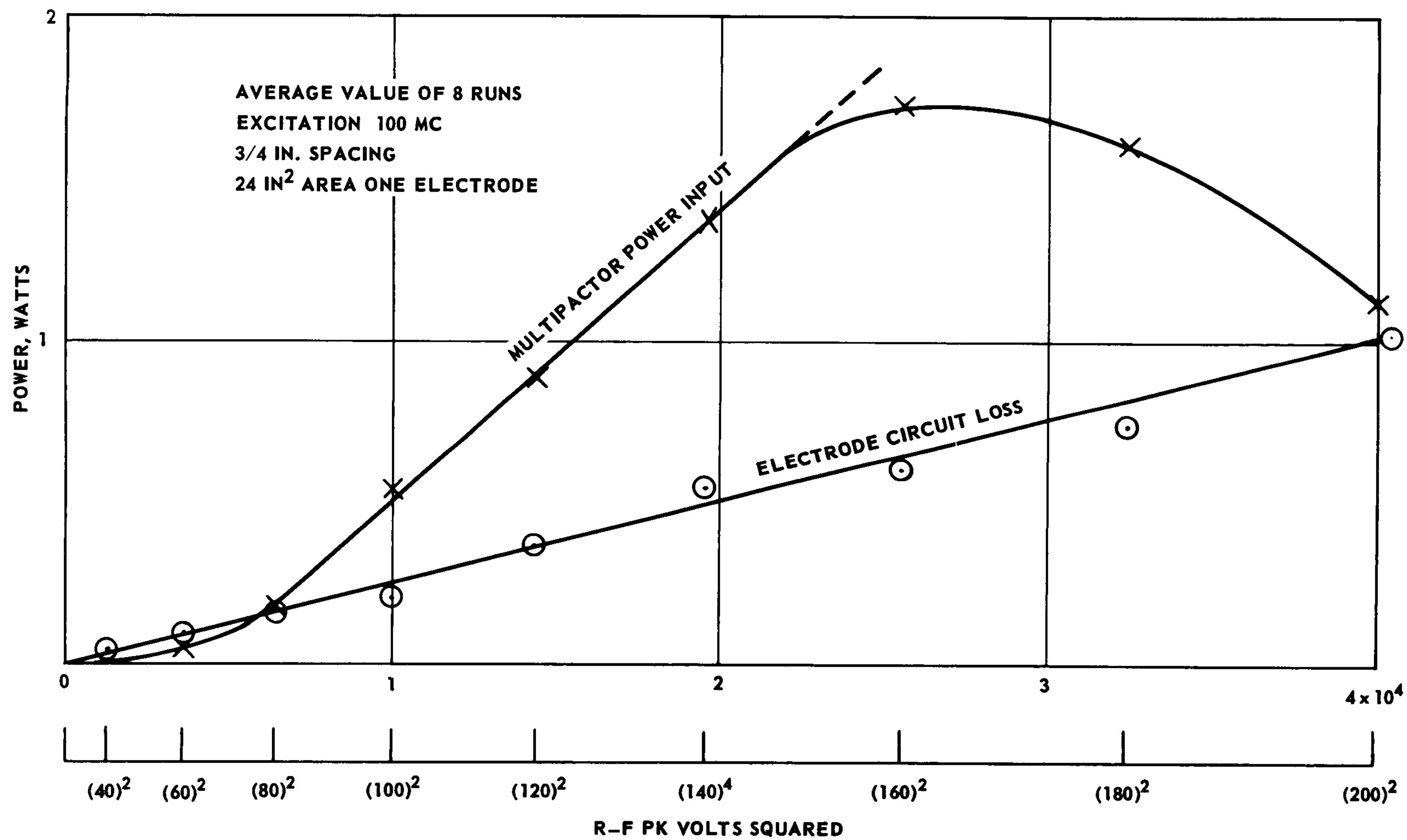

FIGURE 2. POWER VS VOLTS SQUARED

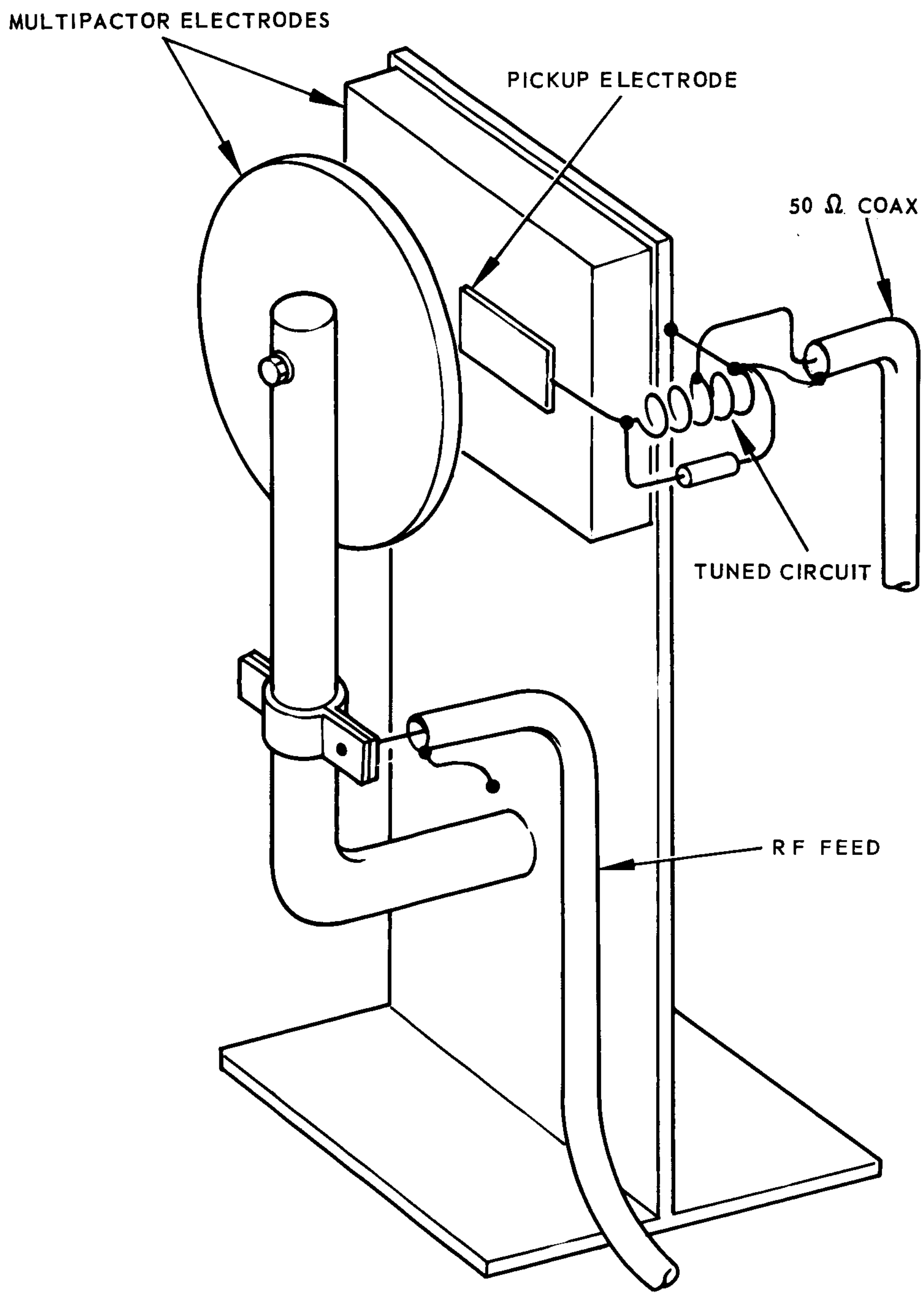

FIGURE 3. NOISE GENERATION EXPERIMENT DETAILS

was adjusted to be resonant at the measurement frequency for each run. The results are shown in Figure 4.

The graph of noise power versus multipactor discharge power shown in Figure 5 represents data taken during 5 hours of operation at a frequency of 112 mc.

For this particular experiment, the multipactor discharge loss is equivalent to a constant shunt resistance from the lowest voltage where the glow is first visible to the point where the glow starts to spread through the chamber.

The next experiments will be directed toward determining the total noise power in the discharge, and the noise currents which flow in the electrodes. The signal which is picked up is due to a combination of discharge electron interception and capacitive coupling from the electrodes, but the relative magnitudes of these two effects are not yet known.

C. PERFORMANCE AND WORK SCHEDULE

A total of 580 manhours was spent on the project during December, divided among the tasks as follows:

Task I	180 manhours
Task II	200 manhours
Task III	200 manhours

The program is on schedule and should be completed by 15 March 1965.

D. CONTRACT FUNDING

Present funds are adequate to complete the program on schedule. The planned equivalent manpower schedule for the remainder of the contract is as shown below:

	January	February	March	
All Tasks	560	540	0	manhours
Final Report	0	130	130	manhours

E. CONTRACT PERSONNEL

There have been no personnel changes during this period.

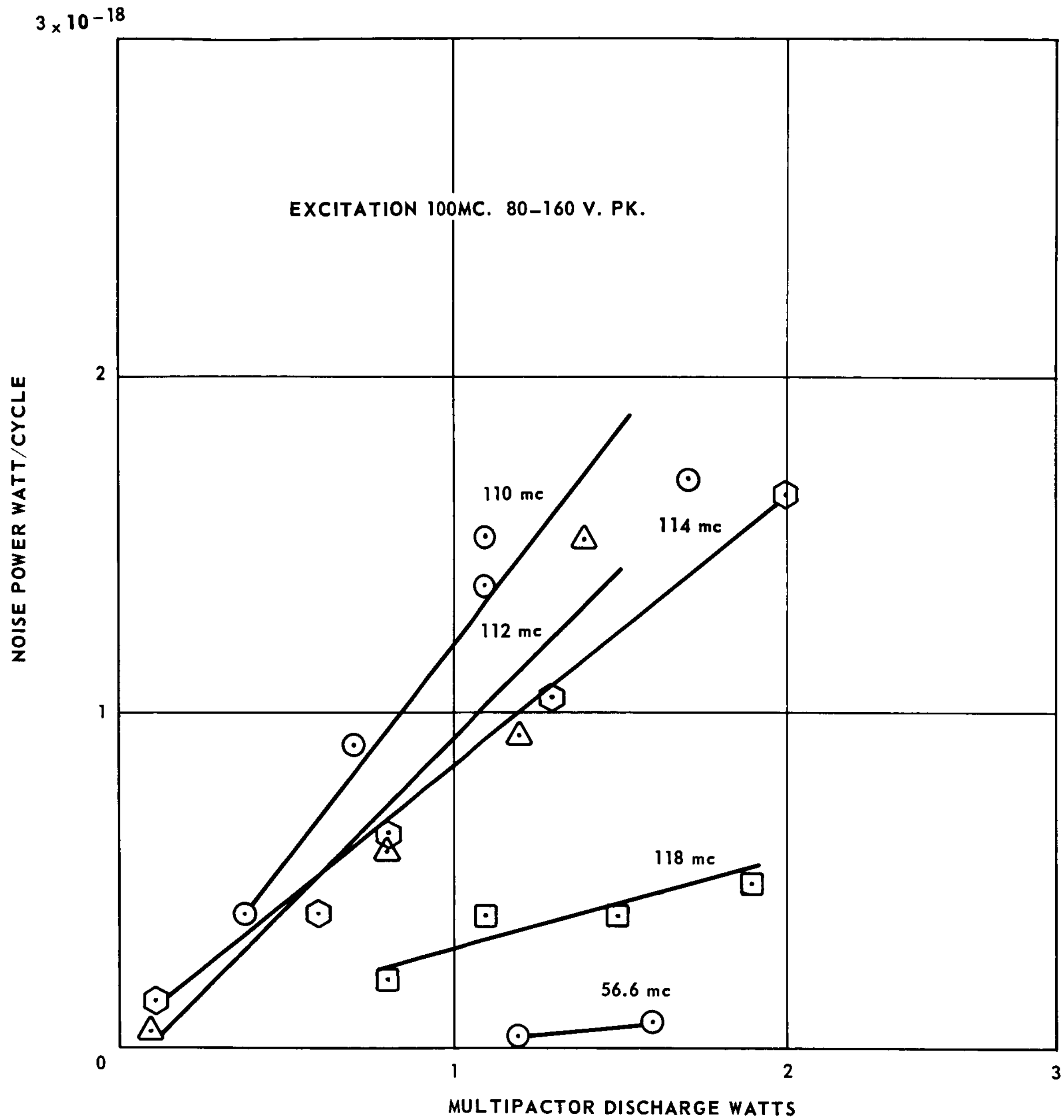

FIGURE 4. MULTIPACTOR NOISE – FREQUENCY MEASUREMENTS

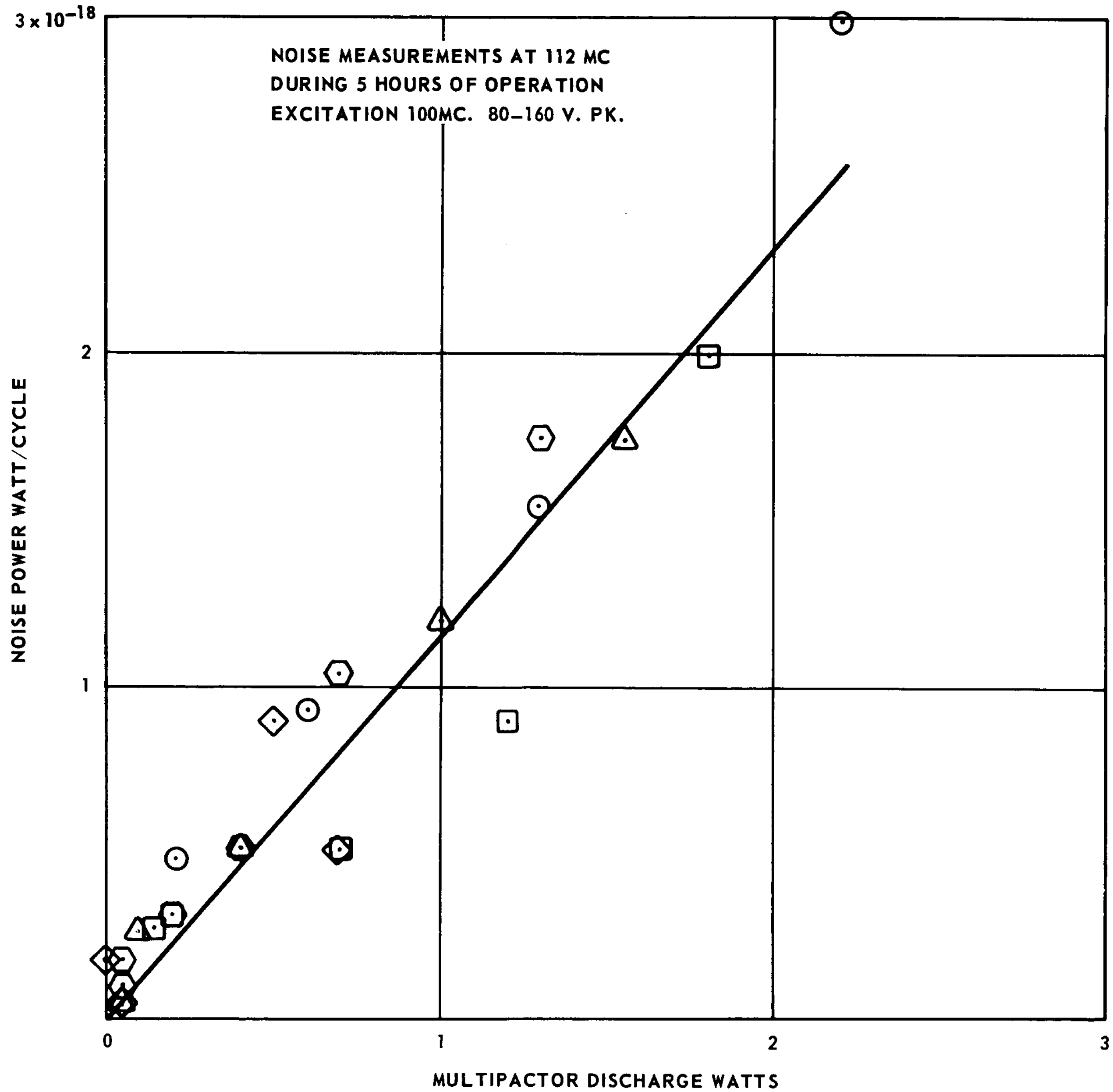

FIGURE 5. MULTIPACTOR NOISE AT 112 MC

F. PROGRAM FOR NEXT INTERVAL

During the next month efforts to get useful results from the high vacuum experiment will continue. Additional tests of enhanced secondary emitter electrodes will be conducted. The harmonic generator test results will be analyzed to determine cross modulation coefficients, and a cross modulation experiment will be designed. If time permits, experiments will be conducted to get a better estimate of the detuning effects of the multipactor electron cloud. Further noise generation tests will be conducted to determine more about the frequency dependence of the generated noise, and to attempt to correlate the magnitude of the generated noise with the shot noise which would be generated by an equivalent electron current. Measurements will be started to determine the effectiveness of thin titanium films in suppressing multipactor in a typical RF structure.